Proton Plan
Proton Projections
Accelerator Division Review
August 2005

Eric Prebys

Outline

- Projection Procedure
- Status of 2005 projections
- Revisions for future
- Long term projections
- Conclusions

Procedure for estimating Proton Delivery

- Assume traditional operational priority:
  - Protons for pBar production
    - Limited by ability to slip stack
    - Limited by max cooling rate
  - Protons for NuMI
    - Limited by max Booster batch size
    - Limited by max MI cycle rate
    - Limited by max MI proton capacity
    - (will be) limited by ability to slip stack NuMI protons in MI
  - Protons for BNB (currently MiniBooNE)
    - Determined by difference between Booster capacity and maximum MI loading.
    - Currently limited by Booster losses, and will continue to be for some time.
    - Ultimately limited by Booster rep. rate.
    - *Extremely* sensitive to fluctuations in total Booster output

Evaluate Effect of Booster Improvements

- Calculate effect of various improvements based on increased acceptance:
- Use:

$$A = \delta A + \sqrt{\frac{\beta_T \varepsilon_{\max}}{\beta\gamma} + \left(D\frac{\Delta p}{p}\right)^2} \quad \Rightarrow \quad \varepsilon_{\max} = \frac{\beta\gamma}{\beta_T}\left((A-\delta A)^2 - \left(D\frac{\Delta p}{p}\right)^2\right)$$

Effective aperture reduction

Improvement	Date	δA_x (mm)	$\beta_{x,\max}$ (m)	$D_{x,\max}$ (m)	δA_y (mm)	$\beta_{y,\max}$ (m)	ε_x (π-mm-mr)	ε_x (π-mm-mr)	Rel. total	Incr.
Initial	---	10	45.8	6.2	4	24	15.0	15.0	85.3%	
Dogleg 3 Fix	10/03	10	40.8	4.5	4	24	17.6	15.0	100.0%	17.3%
Dogleg 13 Fix	10/04	10	36.1	3.8	4	24	20.2	15.0	114.6%	14.6%
Booster Dump Relocation	12/05	10	34.9	3.5	4	24	21.0	15.0	119.1%	4.0%
ORBUMP/400 MeV upgrade	12/05	5	34.9	3.5	4	24	29.5	15.0	167.8%	40.9%
Correctors (dipoles)	10/07	2	34.9	3.5	2	24	35.4	18.3	245.6%	46.3%

Additional Effects

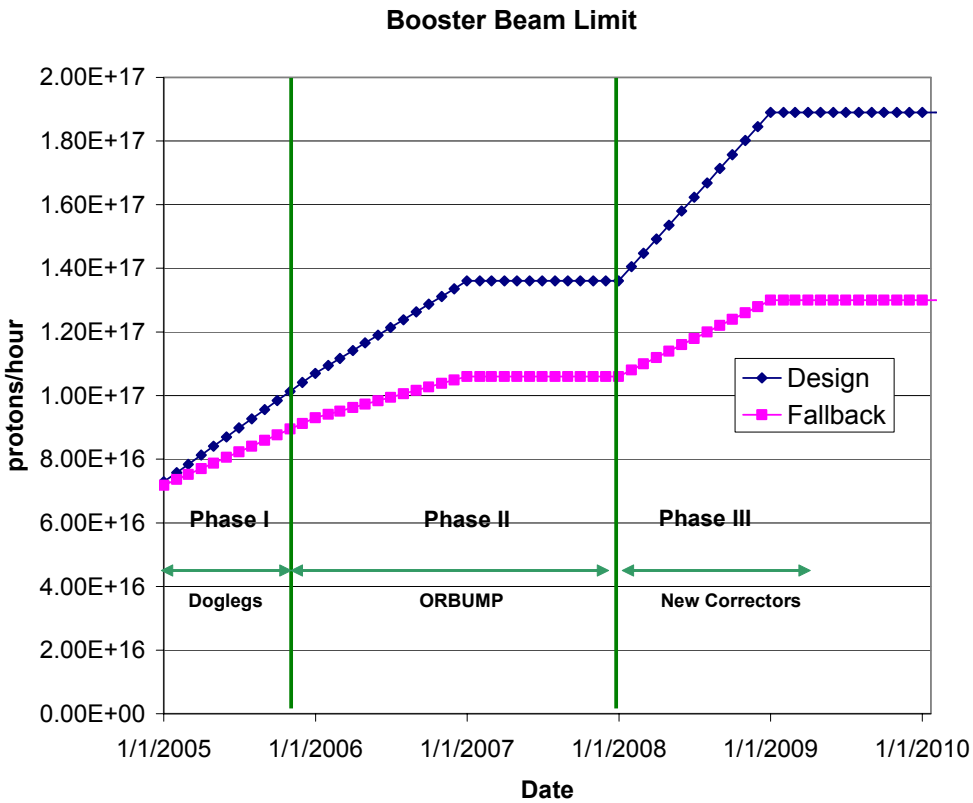
- Increased transmission once Long 13 is removed
  - 3%
  - Probably conservative
- Effect of sparse sextupole correctors on emmittance
  - ~10%
  - Does not yet include significantly improved harmonic corrections
- Effect of Booster RF improvements
  - ~5% increased uptime
- Effect of Linac Low Level RF
  - ~5% improvement on average beam intensity

Estimating Booster Output

- History has shown that the lab tends to overestimate the benefits of particular improvements.
  - Tuning and optimization take a long time
  - Tend to asymptotically approach the goal, then get distracted by other things.
- So we…
  - Evaluate the potential of particular improvements based on effective aperture increase or uncontrolled beam loss reduction:
    - For example, if something reduces uncontrolled loss by 10%, it has the potential to allow us to send 10% more beam.
  - Consider the following scenarios:
    - "Design": After *one year* of tuning, we realize *half* of the potential benefit.
    - "Fallback": After *one year* of tuning, we realize *one quarter* of the potential benefit.

Peak Booster Intensities

Date	"Design" Limit (1E16 p/hr)	"Fallback" Limit (1E16 p/hr)	Comment
1/2006	10.7	9.3	Effect of collimators, dogleg fix, plus some alignment
1/2007	13.6	10.6	Alignment, ORBUMP, and L13
1/2008	18.9	13.0	New corrector system



- These are "peak" numbers
- An "average to peak" correction is applied to get average values

Proton Projections

- Phases of Operation
  - Phase I
    - After 2004 shutdown (now)
    - Lattice problems ameliorated
    - Booster limited to 7.5Hz total repetition rate
    - Ramp up to 2+5 Main Injector operation
  - Phase II
    - After 2005 shutdown
    - Booster capable of ~9Hz operations
    - MI still running in 2+5 mode
    - Increase beam to BNB
  - Phase III
    - Slip stacked (2+9) operation to NuMI
      - Possibly requires RF upgrade
    - Beam to BNB as allowed by increase Proton Source capacity

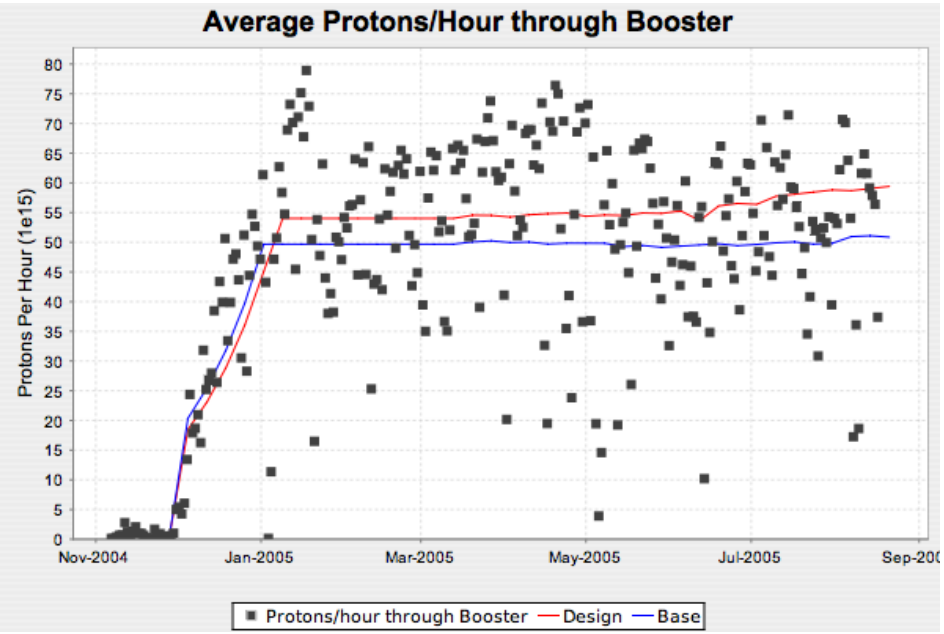
Factors Considered in Projections

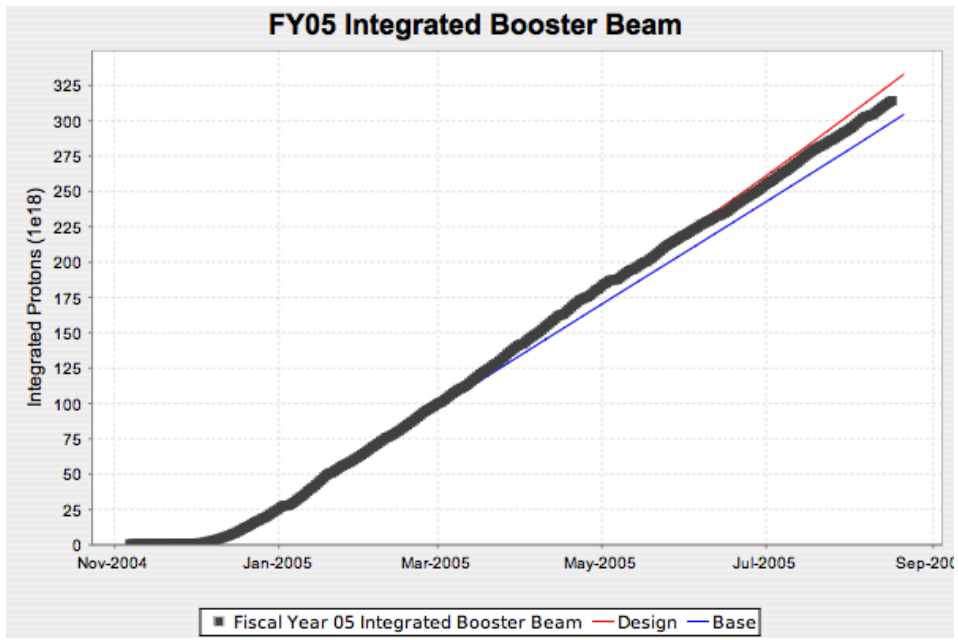
- Linear ramp-up to see benefit of improvements
- Slip stacking efficiency
- Annual shutdowns (assume 2 mo/yr)
- Uptimes: based on 2004
- Peak to average corrections
  - For BNB, based on MiniBooNE 2004
  - For NuMI, used reasonable guess
- Effects of shot setup
- Implemented as VB routines in Excel spreadsheet
  - Easy to modify

How are we doing so far?

- Total Booster output:
  - Compare actual to projections from Nov., 2004 Proton Plan document
- Individual NuMI/MiniBooNE:
  - Compare actual to revised NuMI ramp/up from ~2/05
  - Note:
    - No allowance for NuMI target problems
    - No correction for pBar slip stacking problems
      - Good for MiniBooNE
      - Bad for NuMI

This Year: Total Proton Rate

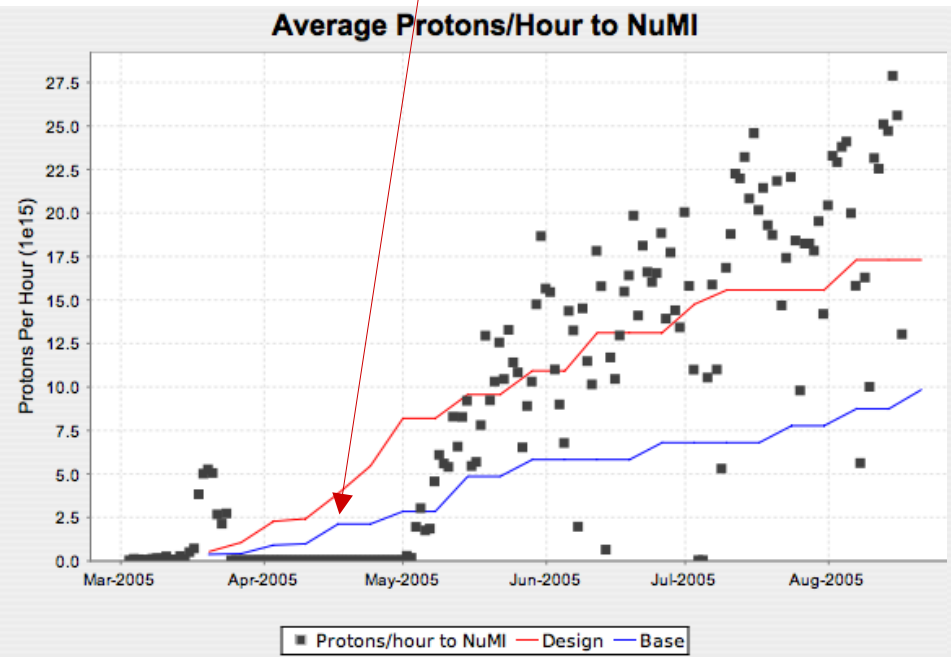


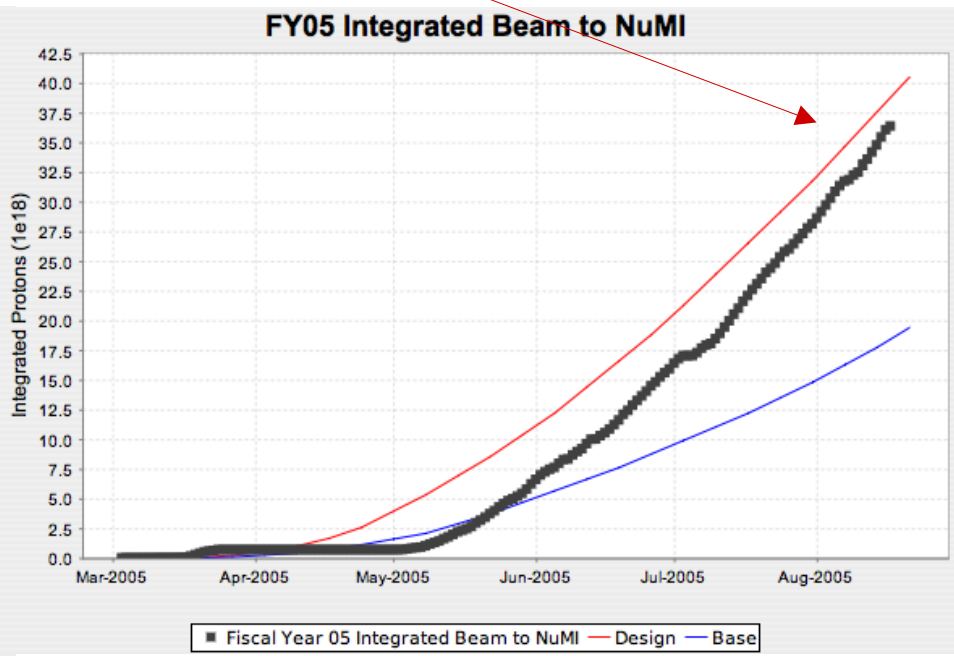


Protons to NuMI

NuMI Target Failure

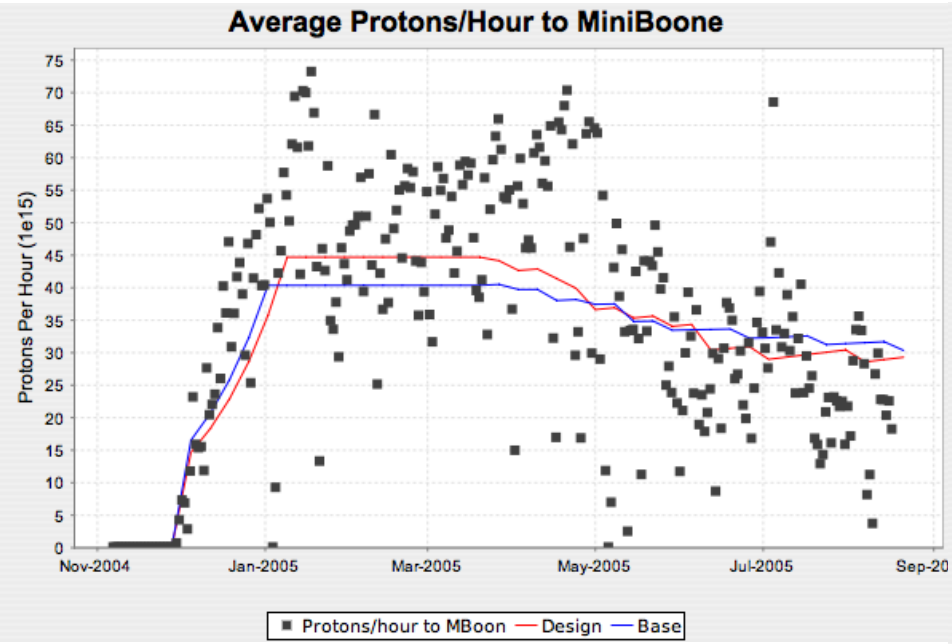
Almost caught up

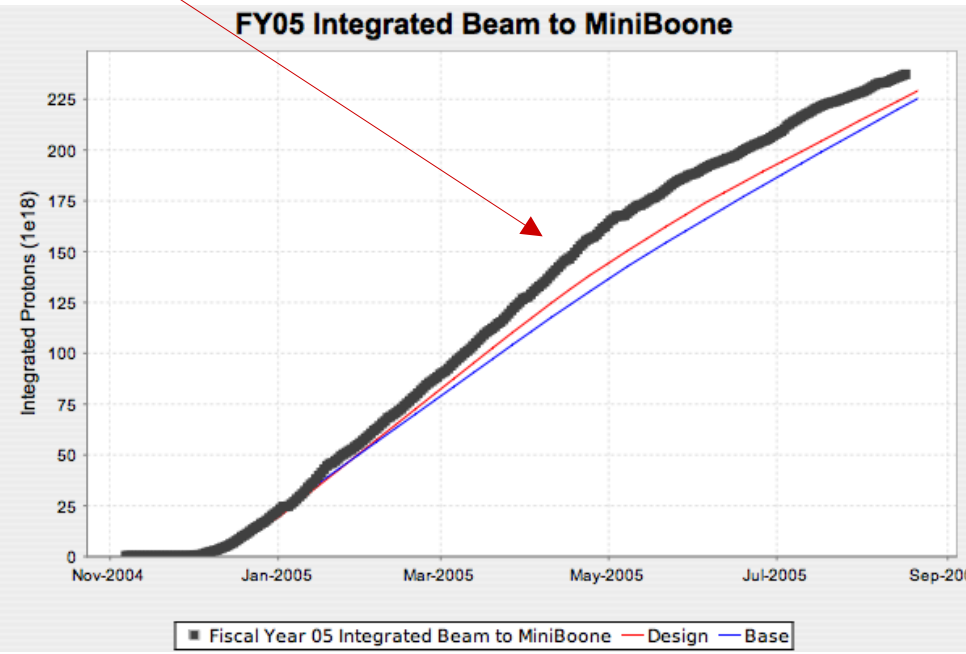




BNB (MiniBooNE)

Benefited from NuMI's problems





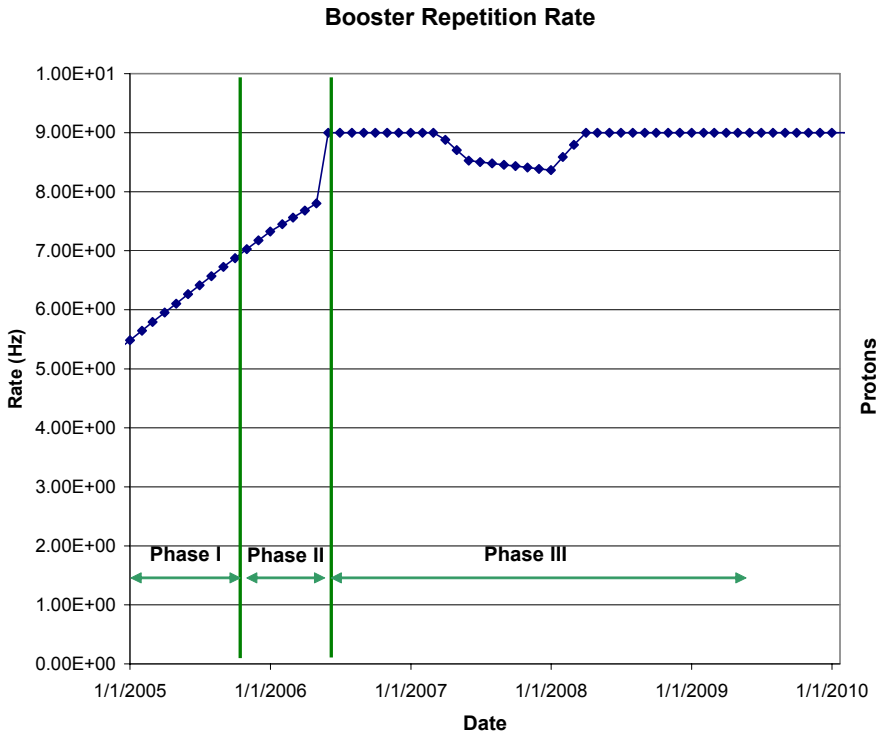
Summary of Tracking to Date

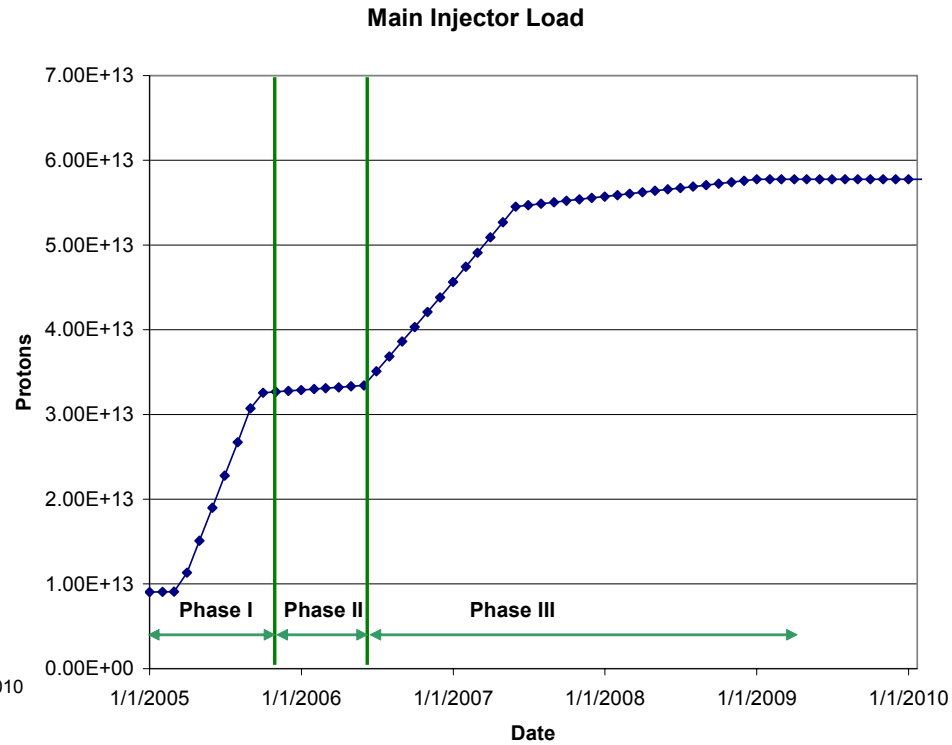
- Things we did well on:
  - Average total proton rate
    - More or less on track
  - NuMI load per batch
    - Predicted: ~1.5E13
    - Actual: ~2.1E13
- Things we've missed on
  - Batch intensity
    - Assumed 5E12 based on 2004
    - Actual ~4E12
    - Largely tuning philosophy
  - Main Injector cycle rate
    - Assumed we'd be locked to 2 second rep rate by now
  - Slip stacking performance
    - Good for NuMI so far
    - Bad long term

Modifications for Long Term Projections

- More realistic batch intensity
  - Before: 5.0E12 -> 5.5E12 (peak) over next three years
  - Now: 4.5E12->5.25E12 over next five years
- Assume lower slip stacking performance
  - Before: slip stack at 90% of peak batch intensity
  - Now: slip stack at 80% of peak batch intensity (i.e., we'll achieve (9*4E12 per cycle to NuMI)
- However
  - Now assume NuMI running during shot setup
  - Effects of Linac LLRF and Booster RF on efficiency

Machine Loading





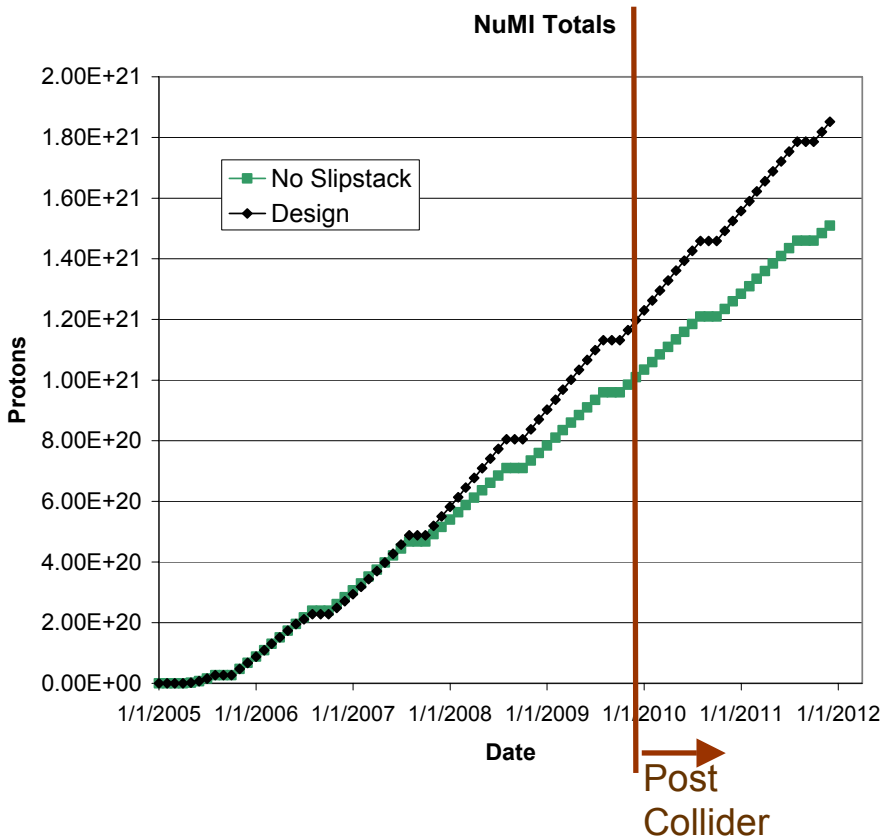
"Design" PoT

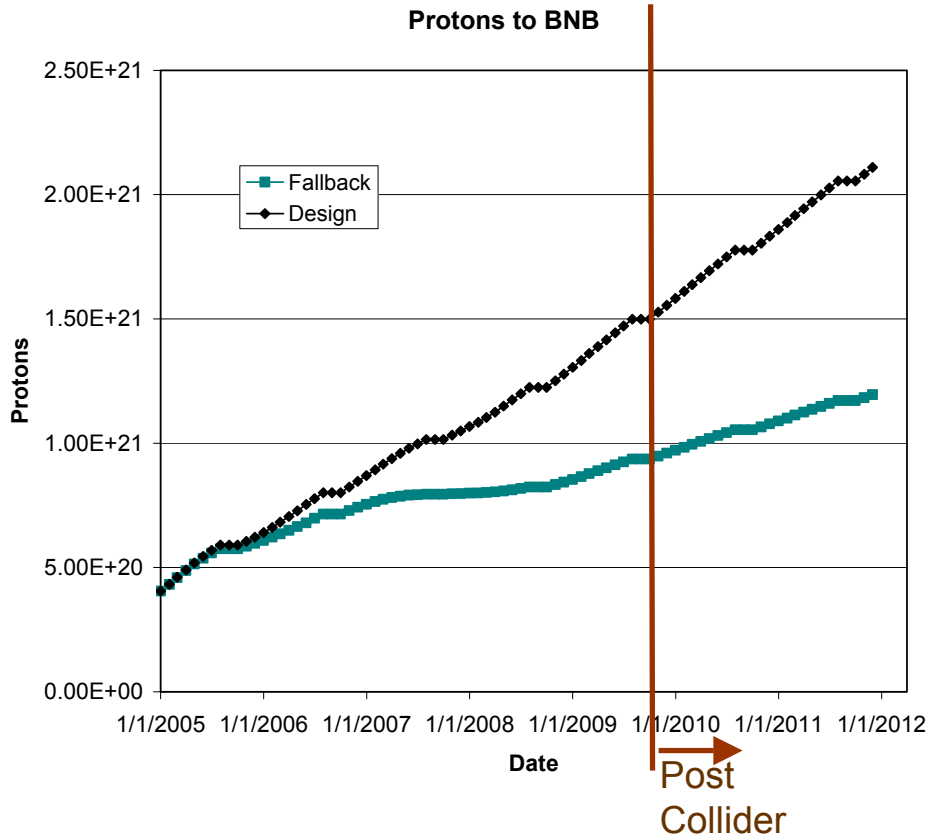
	Booster Batch Size	Main Injector Load	Cycle Time	MI Intensity	Booster Rate*	Total Proton Rate	Annual Rate at end of Phase	
		(AP + NuMI)	(sec)	(protons)	(Hz)	(p/hr)	NuMI	BNB
Actual Operation								
July, 04	5.0E+12	1+0	2.0	0.5E+13	5.3	0.7E+17	0	3.3E+20
Proton Plan								
Phase I	4.7E+12	2+1→2+5	2.0	3.3E+13	7.3	1.1E+17	2.2E+20	2.1E+20
Phase II	4.9E+12	2+5	2.0	3.4E+13	8.7	1.4E+17	2.3E+20	3.5E+20
Phase III	5.3E+12	2+9	2.2	5.8E+13	9.0	1.9E+17	3.3E+20	2.8E+20

Peak values

Averages

Cumulative Totals





- Note: these projections do *not* take into account the collider turning off in 2009
  - NuMI rates would go up at least 20%
  - Possibly much higher with Stage II improvements

Conclusions

- The initial proton estimates have been reasonably good for 2005 so far
  - First accurate proton delivery projections ever.
- Many things went right this year:
  - Beam cogging
  - Initial NuMI multibatch operation
  - Simultaneous NuMI/MiniBooNE running
- We have revised estimates for future running
  - Reasonably confident in our estimates for NuMI, *if* slip stacking works.
  - Large inherent uncertainty in estimate for 8 GeV line